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ABSTRACT

We have built several multimedia tutors for science and engineering education. This paper discusses Design for Manufacturing tutors and an electronic homework systems used by over 2000 students daily. The engineering tutors instruct students on efficient procedures for designing parts for manufacture. The goal is to support a deeper understanding of the interaction between features of a part being designed and the corresponding manufacturing requirements of the part in injection molding, sheet metal stamping, and finite element analysis. Animated sequences of the processes are either generated dynamically or indexed according to the possible design. Students create designs, and the tooling complexity is demonstrated through both 2D and 3D animations. (Author)

# Multimedia Tutors for Science and Engineering

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***Abstract*** *– We have built several multimedia tutors for science and engineering education. This paper discuses Design for Manufacturing tutors and an electronic homework systems used by over 2000 students daily. The engineering tutors instruct students on efficient procedures for designing parts for manufacture. The goal is to support a deeper understanding of the interaction between features of a part being designed and the corresponding manufacturing requirements of the part in injection molding, sheet metal stamping, and finite element analysis Animated sequences of the processes are either generated dynamically or indexed according to the possible designs. Students create designs, and the tooling complexity is demonstrated through both 2D and 3D animations*

## Engineering Problems and Solution

We have developed computer systems which incorporate manufacturing education across the curriculum, addressing the scarcity of manufacturing-oriented engineering professionals and the increasing specialization of faculty. Intelligent tutors and multimedia systems provide students with an opportunity to work on simulated manufacturing projects. The objective is to improve a student's ability to address design problems and to view different manufacturing practices in the context of specific theme processes which are used recurrently throughout the curriculum.

The primary manufacturing problem lies in the sequential mode of manufacturing operation which begins with the conception of an idea for a new product and the subsequent and often isolated process of the design, engineering, and analysis operations. Manufacturing engineers only see the detailed and production drawings after these early steps are accomplished in isolation. The problems are: nearly 70% of the manufacturing cost of a product is determined at the early conceptual stages of design and yet manufacturing is not involved during these early stages; and no single person or group is in charge.

At present, the educational systems provide several features: teach design for manufacturing (DFM) at the early stage in the design process; provide students and faculty with a realistic understanding of manufacturing processes; identify a set of best practices in design for manufacturing; and state-of-the-art Web-based learning environments.

Funded by NSF Engineering Educational and Centers Division Grant No. EEC-9410393 through the Engineering Academy of Southern New England (the Academy), three tutors have been built in addition to an easy-to-search-and-find Web-based information system to enhance a student's access to professional level design-related information.

## Engineering Tutors

The Engineering Tutors address topics such as Injection Molding, Stamping, and Finite Element Analysis. They constrain students' design choices, provide straightforward feedback and show a library of visualizations produced by commercial off the shelf systems. The power of the tutors comes from three sources: students interact with content to accomplish a design task; tutors provide immediate feedback (unlike handed-in assignments); and 3-D visualizations supply intuition behind complex geometric problems.

### Injection Molding Tutor

The Injection Molding Tutor enables students to construct and examine molded polymer part designs, adding features such as bosses, `thru' holes and tabs. The Tutor provides an animated 3D tooling solution for the student's design, critiques the design, advises about relative cost, and proposes alternative designs to save money. It constrains the students' design choices, provides straightforward feedback and shows a library of visualizations produced by commercial off-the-shelf systems

The Tutor shows an animation of an injection molding machine along with a simple open/shut mold, see Figure 1. The student then creates new designs, using either an "L-braket" or a box as the base, see Figure 2. The student selects features to add and then defines the mold closure direction. The Tutor then critiques the student's design and a color animation of tooling that would be required to produce the part design is displayed.

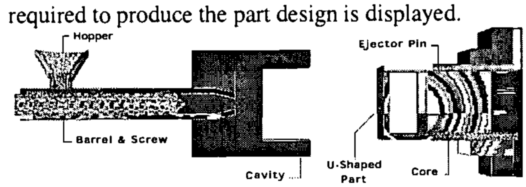
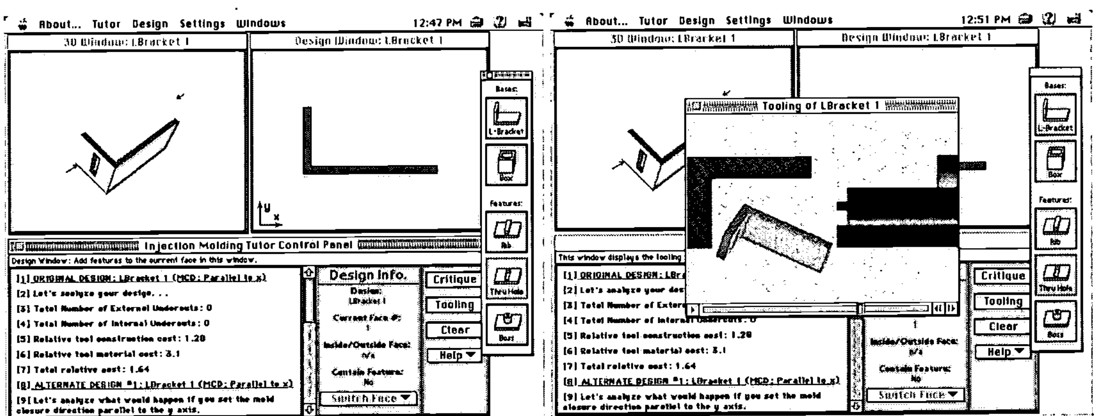



*Figure 1. Injection Molding tooling required to produce a simple U-shaped part.*




(a) (b)

*Figure 2. Critique (a) and tooling animation (b) for an L-bracket.*

## Stamping Tutor

The Stamping Tutor helps a student understand the relationship between sheet metal part design and required stamping stations. The Tutor identifies design issues including: dissimilar features, closely spaced features, narrow cutouts and projections and bends. It demonstrates how many stamping stations are needed for each design through both 2D and 3D animations. Then the student designs a part within an interactive environment, see Figure 3. Using an underlying internal representation of rules, the Tutor dynamically generates an animation of the proper number of moving stamping stations required to build the part, see Figure 4. The Tutor also provides a non-intrusive critique explaining why the features chosen may result in an inefficient design. Currently, a cross-platform introduction, an interactive tutor, and 3D animations of stamping processes are available for distribution.

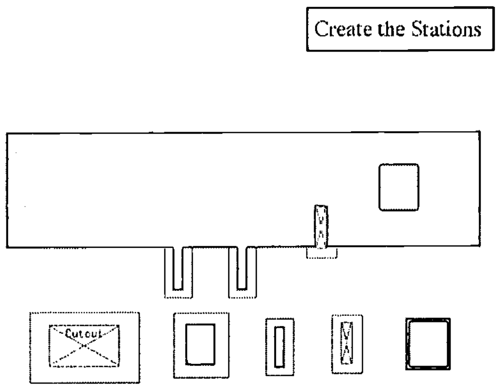



*Figure 3. Students use an interactive environment to design a stamped part, moving cut outs, through holes, and thin or narrow projections onto a blank metal part.*

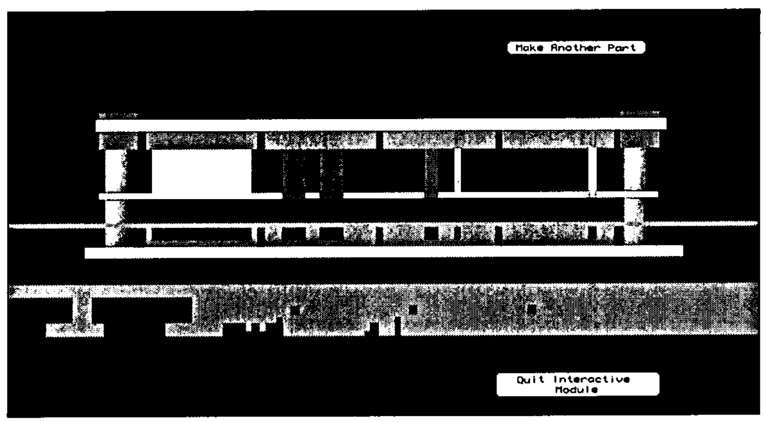



*Figure 4. The tutor reasons about the student's design in Figure 3 and produces an animation of the four stamping stations required to make the student's part.*

## Finite Element Analysis Tutor

The FEA Tutor improves the ability of undergraduate mechanical and civil engineering students to address real-world design problems which are typically analyzed using computer-based finite element analysis (FEA) tools. The Tutor illustrates how complex physical systems can be transformed into simple representations and highlights when FEA should and should not be used.

This self-standing, Windows-based intelligent interactive software program teaches the basic principles, concepts and guidelines involved in finite element analysis. The Tutor describes FEA, identifies when it should and should not be used, illustrates the concepts of modeling and analysis and then articulates the process of proceeding from a real-world problem to a solution through modeling, discretization, analysis and results interpretation. Several physical objects are provided and students are asked to identify the symmetry, see Figure 5.

Another part of the tutor teaches that modeling is the cognitive process of transforming a complex physical system to a simplified representation and when to make modeling simplifications. The discretization module teaches basic element and node concepts and discretization. The finite element solution is an approximate one. Since discretization is closely coupled to the concept of convergence, both of these concepts are taught in this module.

It presents a predefined model, loads, and boundary conditions and asks the student to determine the necessary level of mesh refinement required for the

solution of interest (i.e. maximum deflection or stress) to converge to within a specific tolerance of the exact solution (see Figure 6). Results for all possible mesh refinement levels are stored in the Tutor database. The Tutor plots the solution item of interest versus mesh refinement level in a window, as well as the estimated cost of each analysis and the cumulative analysis costs. The student is critiqued based on the total analysis costs and mesh refinement level the student believes is necessary for convergence.

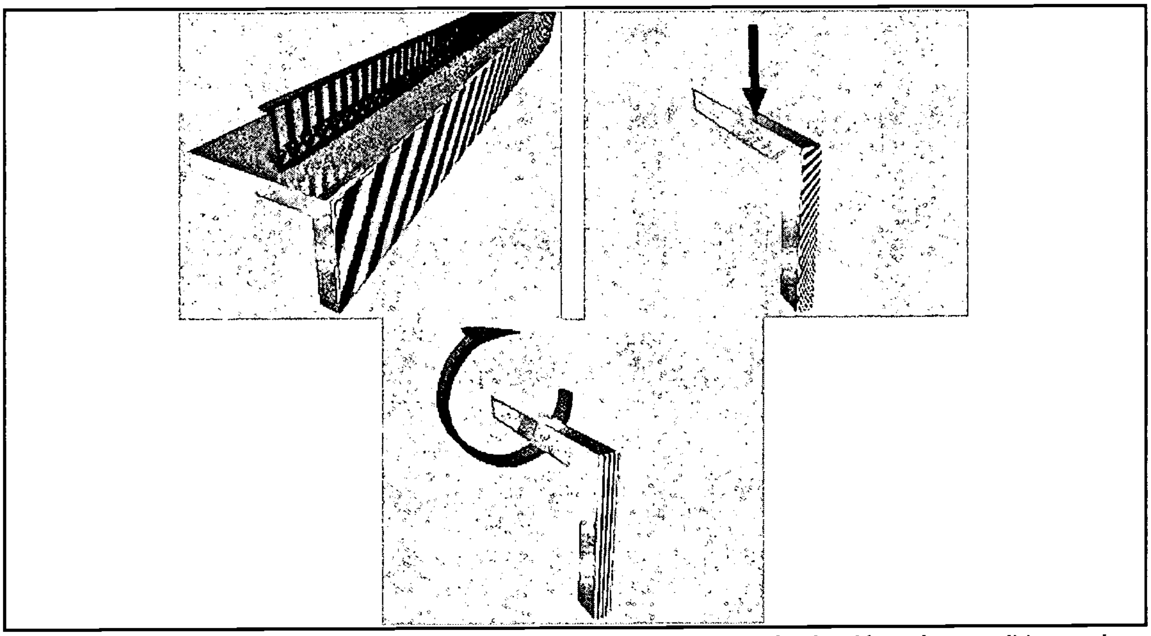
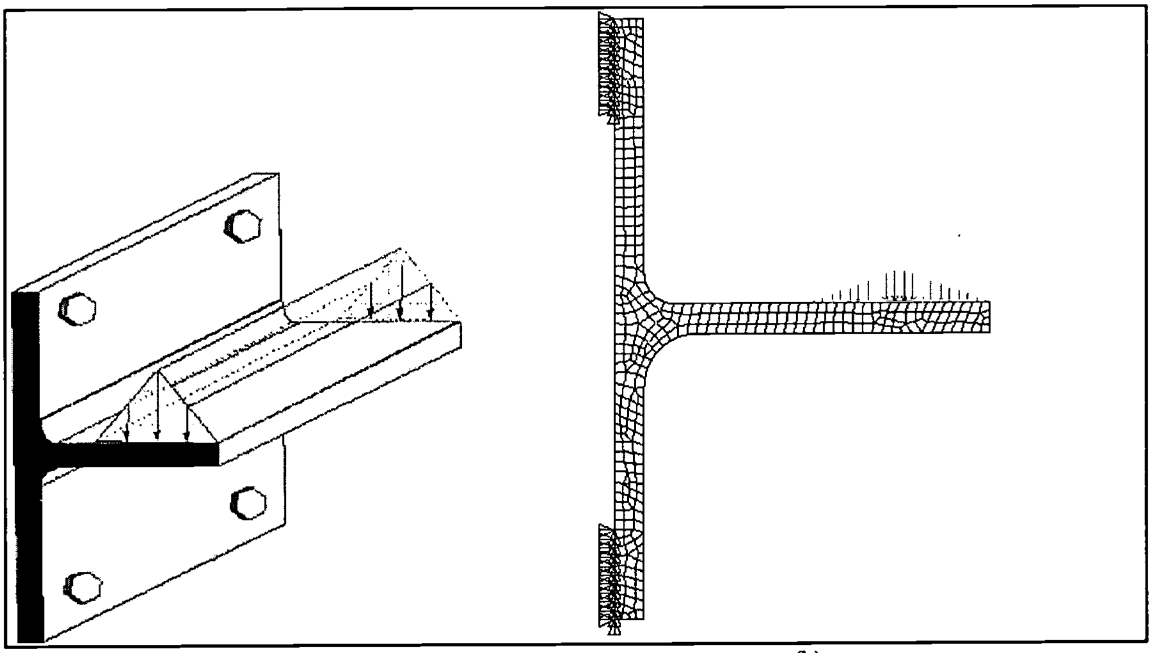


*Figure 5. The FEA Tutor teaches the basic concepts of model symmetry, load and boundary conditions and dimensional symmetry, including axisymmetry, plane stress and plane strain, and feature elimination.*



(a) (b)

*Figure 6. The Tutor presents a student with predefined model (a), load and boundary conditions and ask for the necessary level of mesh refinement required (b).*

Real-world problems, such as a long pipe under internal pressure and the shrink fitting of a collar onto a shaft, are animated to give the student a very visual representation of the lesson material. At the end of the modeling component, an experiential module challenges the student to construct appropriate simplified models for a number of analysis problems. If the student has failed several times in a row, the system responds with the correct model and the reason why this model is the most appropriate.

## Electronic Homework System

Our electronic homework system supports web delivery of questions, answers and feedback. It serves over 2000 students daily and is used by both the Physics and Chemistry Departments and at two universities. Extensive authoring tools support generation of new questions, question delivery, parameterized questions and the encoding of graphics and animations, and feedback drivers with multiple answers.

Interactive discovery modules track the student's performance and provide interactive simulations and an incentive to perform the learning activity. Twenty interactive discovery environments have been developed in Java including topics such as radioactive decay, orbital energies, uv-vis spectroscopy, chemical equilibrium and acids and bases (funding by NSF, DUE-9653064 and Department of Education, FIPSE). In an integrated environment, the student is led to interact with the applets through specific questions. The initial questions help the student discover how to interact with the applet and additional questions help assimilate observations, formulate and test hypotheses, or reach conclusions. Initial response to these environments from students in the pilot group was favorable as they interacted with the limiting reagents and electromagnetic radiation applets.

The second tutor on "molecular structure" serves as a prototype for subject areas that are visual in nature, and in which students directly manipulate images, see Figure 7. In this tutor, the student constructs Lewis diagrams using a palette of tools for placing and moving symbols for atoms, bonds, and electrons

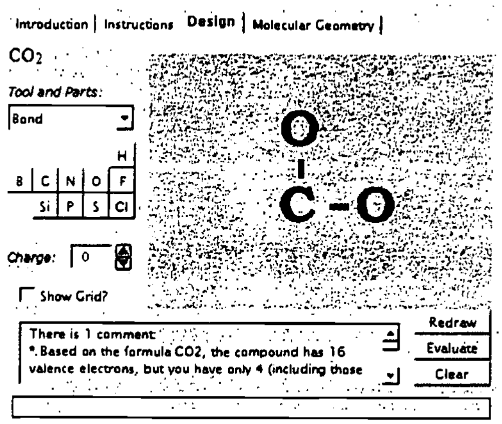



*Figure 7. The Lewis Structure Tutor*

## Evaluations

We evaluated the engineering and chemistry tutors and showed that they are as effective as several hours of lectures and homework assignments within a traditional classroom setting. For example, the Injection Molding Tutor was evaluated with more than 100 students at UConn and UMass/Amherst, see Table 1. Six groups of students were tested: Groups 1 &3 used the Tutor first and then attended several lectures and completed homework, Groups 2 & 4 attended lectures first and then used the Tutor and Groups 5 & 6 either attended lectures or used the Tutor exclusively. A written test, with a total score of 32, was administered after each activity, Tutor or lecture. Students who did not attend lectures and only used the Tutor understood the relationship between part geometry and tool complexity as well as the traditional students. One exception was the case of lecturer A who is a domain expert in manufacturing and the author of the software. In all other cases, where the professor was not an expert in Injection Molding, the results indicate that students using only the Tutor were as knowledgeable about the relationship of part geometry and tool construction difficulty as those who had the advantage of being exposed to a domain expert.

The Fea Tutor was evaluated with twenty-five students. One group used the tutor and had no other formal instruction and the second attended a 45 minute lecture in FEA modeling. A homework assignment involved modeling a cylindrical pressure vessel and two different cap attachments methods: mating the end cap with a continuous circumferential weld or bolting the end cap flanges to the tank using a uniform 18 bolt pattern around the cap. The students who used the FEA Tutor performed 30% better than those that attended the traditional lecture.

## Conclusion

The goal of this work is twofold: to communicate complex engineering and science knowledge and to enable students to receive more immediate and active feedback customized to their individual learning needs. The systems described above have been demonstrated to over a hundred faculty at more than twenty national and international conferences. They are all cross-platform and available for distribution. We are now conducting summative evaluation on the systems at two and four year colleges, and for a variety of students, including women and minorities. We are working on complete evaluation studies, wide dissemination and a commercialization plan for these systems.

The IMT and Stamping Tutors have been pressed to CD-ROM and are available. The IMT tutor is also available on the Web at http://www.ecs.umass.edu/mie/dfm/imm.html. For more information about the electronic homework system click on "OWL Overview" at our web site http://owl.chem.umass.edu/. The FEA Tutor can be downloaded using FTP protocol from medo1.ecs.umass.edu. FTP logon under the account name NSFFEA with the same password. Get the file featutor.zip and use WinZip to extract the file.

| Lecturer | | Tutor First | Lecture Second | Lecture First | Tutor Second |
|---|---|---|---|---|---|
| 1,2 | Lecturer A* | 16 | 25 | 23 | 23 |
| 3,4 | Lecturer B | 13 | 14 | 12 | 9.6 |

| Lecturer | | Tutor First | Lecture Second | Lecture First | Tutor Second |
|---|---|---|---|---|---|
| 5 | Lecturer C | | | 16 | |
| 6 | Software only | 17 | | | |

Table 1: Evaluation of Learning Using the Injection Molding Tutor (Perfect Score = 32)

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